Air Pollution and Urban Morphology: A Complex Relation or How to Optimize the Pedestrian Movement in Town

Gilles Maignant, Jérôme Dutozia

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Gilles Maignant and Jérôme Dutozia
CNRS, UMR ESPACE,
University of Nice-Sophia Antipolis, Nice,
France

1. Introduction

1.1 Understand the air pollution in town - modelling aspect

Urban air pollution is traditionally estimated by using techniques based on geostatistical methods, such as interpolation, applied to a set of data stemming from measures of stations of pollution. Now very often, these stations are in insufficient number or do not measure the same pollutants to allow mapping finely dispersion of air pollution through urban spaces. Numerous studies work then from land registries of broadcasts. Although interesting in a regional scale, these studies bring only not enough information in the understanding of the phenomena to a scale as fine as the intra-urban. So, it is necessary to resort to the fine three-dimensional modelling to dread this intra-urban scale and it is what we describe now. Without this aspect of modelling, we cannot work on the intra-urban scale, because in the hypotheses of modelling of the land registries of broadcasts, (figure 1) we consider the homogeneity of the urban morphology, what, naturally, is not the case. The rule of the urban morphology in the dispersal of pollutants will be described in the following paragraph. Let us be interested here in the phase of modelling of the dispersal of pollutants in urban zones.

From modelling point of view, the three dimensional model allows to solve fluid mechanics equations (Navier-Stockes) for each cell of the model. Space is modelled by small boxes (three dimensional cells: eulerian model) for which we applied the equations (figure 1).

$$(1) \quad \frac{\partial \rho}{\partial t} + \vec{\nabla}.(\rho \vec{v}) = 0$$

$$(2) \quad \frac{\partial (\rho \vec{v})}{\partial t} + \vec{\nabla}.(\rho \vec{v} \otimes \vec{v}) = -\vec{\nabla} p + \vec{\nabla}.\bar{\bar{\tau}} + \rho \vec{f}$$

$$(3) \quad \frac{\partial (\rho e)}{\partial t} + \vec{\nabla}.[(\rho e + p)\vec{v}] = \vec{\nabla}.(\bar{\bar{\tau}}.\vec{v}) + \rho \vec{f}.\vec{v} + \vec{\nabla}.\vec{q} + r$$

Fig. 1. The three Navier-Stokes non-linear equations of fluid mechanics

In the figure 1, the first equation describes the preservation of the mass, the second one is for preservation of the impulse, and the third one is for the conservation of energy. Those three equations depicting the fluid mechanics (Navier-Stokes equations) are coupled with the advection and diffusion equation. As the Navier–Stokes equations are nonlinear partial differential equations; the nonlinearity makes most problems difficult to solve in an analytical point of view, that's why we use eulerian model to approximate solutions. For this calculus, by successive approximations, the space is indented as elementary cells for which two types of information are calculated (wind speed and direction, pollutants concentrations).

For each cell we affect one value of polluting flow, and the model calculates the effective concentration after dispersion. The dispersion is estimated by two ways. First of all, we implement the wind field in a specific zone which is not perturbed by the urban morphology that is to say at a high level (200 meters high). After implementing the input data, the model starts running. To stop the model we have two choices, we could stop it after a fixed time (number of iterations) or stop it when concentrations begin stable. We choose the second option and we fixed the stability when differences between concentrations calculated for each cell and for two successive iterations are less than 10^{-6}. So the results are that we could estimate with a fine precision all concentrations in a three dimensional space with a five meters horizontally and two meters vertically resolution (figure 2).

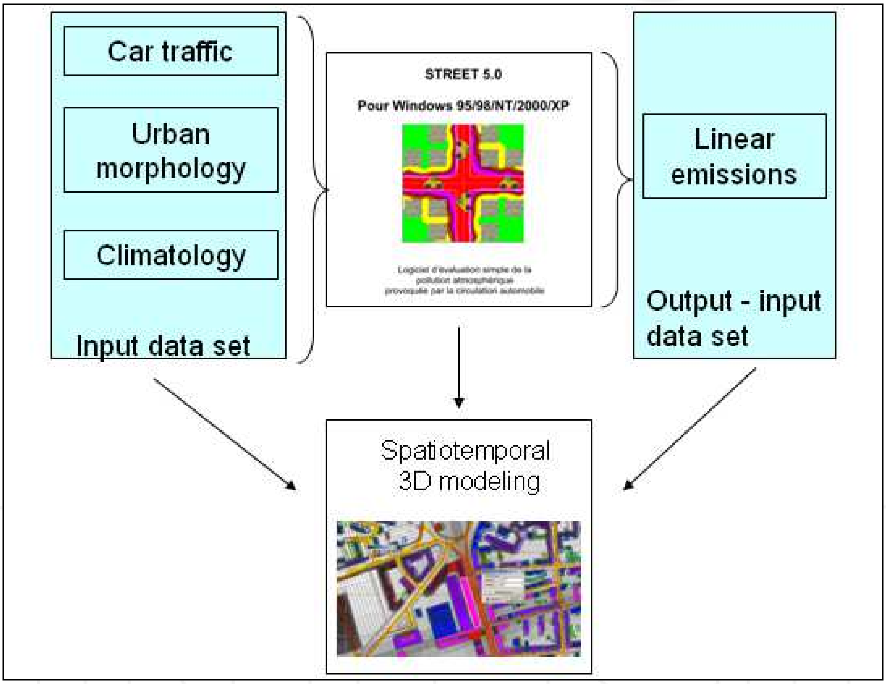

Fig. 2. Air pollution modelling, from sources to maps.

1.2 Why the urban morphology creates spatial differentiations in dispersal of pollutants?

The same broadcasts (emissions) produced in configurations of different streets engender very different polluting loads after dispersal. Now it is indeed these polluting, called immissions loads that interest us within the framework of the problem of the pedestrian routes, because it is about the pollution effectively inhaled by the city-dweller.

Indeed, for the same car traffic, there are spatial configurations of particularly fatal arteries in the dispersal of pollutants (streets canyons) which are "traps with pollutants". It is in these very specific streets that particular attentions in terms of urban planning must be proposed. For example, the “hollow teeth” of the urban morphology should be protected to leave free spaces, useful for a better dispersal of pollutants. In terms of town and country planning, it would be sensible to rethink the filling of these interstitial spaces of a systematic point of view. For example, if the land pressure is such as the filling of these spaces seems to be the only possible alternative, then this measure should be coupled with the institution of a decrease of the traffic on the artery.

The spatial differentiation (gradient of pollution), noticed by a spatial, horizontal point of view, also meets from a vertical point of view (Figure 3). Indeed, spaces near the ground will be more polluted, what will have naturally an influence on the choice of routes particularly at the vulnerable persons whom are the children and the old persons. Furthermore, in the same street, a pavement can be more polluted than the other following one how it is subjected to the wind. All these factors will thus have to take into account for the calculation of an indicator of exposure, which is a function of the length of the chosen arc, the time pasted to go through it (related to the speed of movement of the person) and of the intrinsic vulnerability of the person.

Fig. 3. Building in the centre of Nice, air pollution spatial differentiation (Photo: Gilles MAIGNANT)

2. Optimal pedestrian routes

2.1 Classic vision: from geomarketing approach to societal demand

The problem of itinerary optimization is an old mathematical question, stemming from a problem based on the graphs theory; it knew a new breath thanks to the power of computers. Traditionally, roads are dreaded through software of optimization of type "Chinese post-office employee" or "sales representative", whose purpose is to minimize a cost. These algorithms knew a new breath thanks to the development of strategies of Geomarketing or geo-localization. For instance, the minimisation of emergency services response times (by the Dijkstra or Floyd-Warshall algorithms) and the locating of large infrastructures such as commercial centres, housing developments, leisure centres and transport nodes (train stations, airports etc.) are key considerations in the decision. In the examples which we have dealt with previously, notably in the Geomarketing trend, space is perceived as a constraint in optimisation terminology. This does not mean that it does not play a role, but rather that the objective function is independent from this and could, for example, restore the emergency services response times. This approach is most notably found on online route planning sites such as Via Michelin, Mappy or others on which constraints can be economic, temporal or distance-related; the objective is to find the best possible itinerary which satisfies these user-imposed constraints.

In this approach, the minimization is established on an easily quantifiable criterion (time, outstrips, cost) and does not thus take on character connected to a specific individual. Now in the indicator of exposure which we set up, the subjective vulnerability of the pedestrian is integrated according to three classes at least into the most vulnerable. The more vulnerable is the pedestrian, the more he will be affected by air pollution; that is to say, for the same itinerary, total exposure indicator has to be higher for a pedestrian of vulnerability class 3 than indicator for a pedestrian of vulnerability class 2. This way, attribution of the vulnerability class is very important in our protocol. But this step is also very debatable: why only 3 classes of vulnerability? What should be the more pertinent criterions to allocate the suitable vulnerability class for each pedestrian? As far as we concerned, we consider fuzzy logic could be an interesting methodology to deal with the inherent imprecision related to individual vulnerability evaluation (Bouchon-Meunier, 2007).

The following paragraph has for objective to discuss the foundations of the concept of optimization, its vocabulary and how it is used in this chapter of work.

2.2 Reflection on the optimum

Before question how to applied optimization to the pedestrian movements according to the inhaled polluting load, it seems to us necessary to position the question of the definition of the optimum, particularly in the field of the human and social sciences.

In the *dictionary Larousse*, the definition of *optimum* explicitly refers to a choice between several configurations or fields of possibilities, it is the choice judged most favourable in relation to other solutions or pre-established criteria. This definition, therefore, implicitly demonstrates *optimum* to be a relative term. In other words, the presentation of an *optimum* must not be taken out of context or disassociated from the underlying conditions which have led the modeller to express this *optimum*. The *optimum,* it seems, is always relative to a context or to a particular set of constraints; it is highly dependant on the objective one sets oneself as well as the size and scale of the enquiry. We will now define the notions of context, constraints and objective (Maignant, 2010).

To optimise is to choose the best solution from a spectrum of possible solutions. This supposes a relatively thorough knowledge of the choices available to us (Baquiast, 2007). In the numerous cases presented here, testing all possible configurations is not realistic (too large a number, unknown configurations...); optimisation rests therefore on a selection of choices which seem, in the first instance, to the eyes of those looking to make the optimal choice, the least non-optimal. As soon as we are faced with a choice or with a decision to make, optimisation is present; we look for the best possible solution in relation to one or indeed several fixed objectives as well as to the inherent constraints of the situation (temporal, spatial or financial constraints).

In the case which interests us here, the function "objective" is not directly connected to a cost of economic nature but represents the respiratory hardness to choose a specific urban artery to walk. Here, optimum operates with only one constraint: to minimize pollution exposure during a walking route between point A and point B. Acceptability for this optimal itinerary is relative to individual sensitivity and awareness about air pollution, but also relative to ability of this optimum to not totally take out of distance and travel time constraints.

2.3 Innovative vision

The innovative vision of this chapter lives in the coupling and or the chainage of methods (figure 4). From data of traffic, data of climatology and information on the urban shape, the linear theoretical emissions are calculated in STREET 5.0 (software of estimation of the atmospheric pollution), according to a method of classifications of the various types of vehicles, standards of normalized broadcasts and various cycles of driving including individual behaviour. These theoretical issues are then joined into a three-dimensional model of dispersal of pollutants allowing to produce fine mappings (cartographies) of immissions (precision five meters horizontally and two meters vertically). The model used in this chapter is a three-dimensional model of the fluid mechanics which is non - hydrostatic allowing solving the equations of Navier-Stockes in a space in the complex morphology.

Those average imissions are then joined into a geographical information system to which the module of optimization is applied. The roughness of the route is then modelled through classic spatial constraints (distance, time) and environmental requirements (air pollution) and individual (three classes of vulnerability of the person).

Our system of risk is complex due to considering the vulnerability differentiated by the pedestrians. Indeed, we know that according to the state of health, the age and the biological specificities, the same event will have different impacts on two persons; it is in a sense, a kind of sensibility on the initial conditions. We decided to differentiate three levels of vulnerability, according to which the exposure in the environmental pressure is going to have a more or less strong impact on the health of the pedestrians. For the same route, and thus an exposure amounts, the vulnerable populations, such as the children or the old persons for example, are thus going to be more weakened, than persons not answering particular criteria of vulnerability.

By proposing these comparisons between the environmental optimal routes and the optima in terms of distance, we do not mean there are only two factors influencing the populations in the selection of their pedestrian route. The literature on the behaviour of movements is plentiful, for a state of the recent work on all the criteria which have an influence on the pedestrians in their choices of urban routes, we can refer to Sonya Lavadinho's works and Giuseppe Pini of the University of the mobility of Geneva, who identify more than twenty-five characteristics having a potential impact on the choices of pedestrian routes (Pini, on 2005).

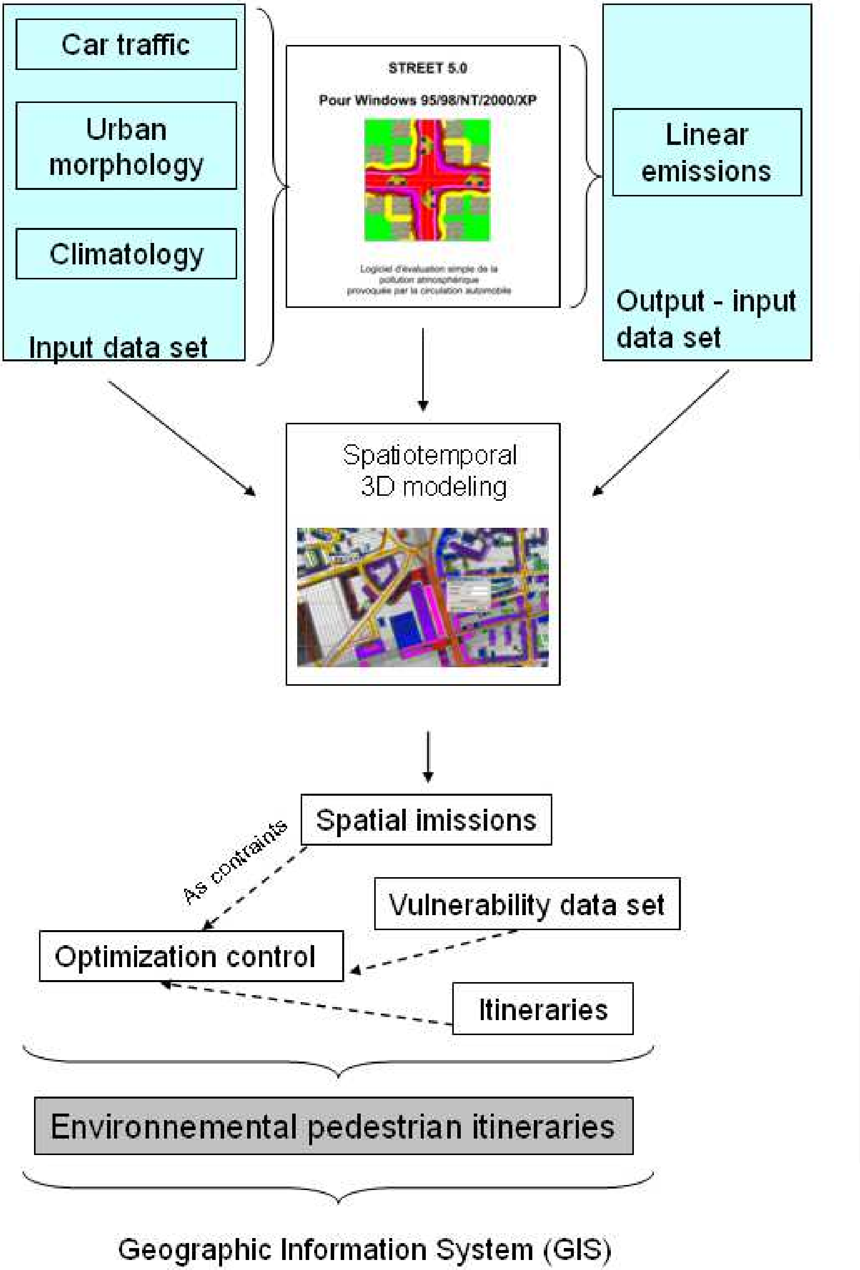

Fig. 4. Scheme of modelization, from air pollution modelling to pedestrian itineraries

To tell the truth, understand what could incite an individual to take an artery rather than the other one is not the subject of our study. We make simply the hypothesis that if a method is able to detect a route minimizing the exposure level in the polluting flows, and if this optimal route is relatively similar to the optimum outstrip time, then this plan will be considered as acceptable for a part of the population. This threshold of acceptability is not fixed but can vary according to the pedestrian, to its practices, characteristics and the purpose of its movement. On the other hand, dealing with of the difference between the plans of the optimal routes in distance (OD) and the optimal routes in terms of environment (OE), we should not neglect the importance of the time of movement (which is also the time of exposure), integrated into the formulation of the indicator of exposure through the factor length of the route.

In this chapter's book, we voluntarily simplified the application by considering that about their levels of vulnerability, the populations move in an identical and constant speed. So, the time of exposure varies only according to the length of arteries. If we had considered various types of pedestrian movements, by distinguishing for example a walking mode and a chasing mode, the modelled system would have been much more complex due to the strong interactions between speed of movement, time of exposure and volume of inhaled air. In running position, an individual moves approximately in 15 kph while he moves only in 5 kph by walking. So, the runner is going to reduce sharply his exposure time; but its global level of exposure in pollutants will not fall inevitably, because decline of the time of exhibition, which could be calculated in our indicator by balancing the distance by a value lower than 1, will be compensated with the sharp rise.

The search for an optimal route consists in identifying the route which minimizes the time, the necessary distance or the economic cost, to connect one point A to one point B. The notion of optimum leans here on the other preoccupations, because the methodology proposed here, aims at the detection of pedestrian routes minimizing the environmental pressure undergone by the pedestrians. In town, various types of routes offer themselves to the pedestrian. More or less consciously and more or less effectively, people select their road according to their constraints. The workers tend to privilege the shortest road at time, whereas the walker will choose more a good quality road environmental especially if he coincides with centres of proprietary (cultural or environmental) interests or spaces offered to the view. One of the preoccupations of the planners could be to conciliate visual interests sites (architectural, landscapes etc.) with routes of better environmental qualities.

From here, for a given route, the time of route is inevitably equal in the time of exposure of the pedestrian to a variable load of pollutants, one of the objectives of the approach is to know if it's better to take the shortest road but very polluted rather than a very long and little polluted road? Several categories of bows occur: long and polluted bow, short and healthy bow, short and polluted bow, long and healthy bow. The first one is not an optimum and it is evident that nobody is going to take it, the second is an absolute optimum but does not exist frequently in the reality (otherwise everybody would take it) ; both last ones constitute the heart of the discussion.

Is it better to take a short arc but polluted rather than a long but healthy arc? If we consider only one of the factors outstrip or environment, it is easy to decide between these two roads. The complexity comes to have to integrate into the indicator two factors which are not of the same order. But the length of the route influences strongly the possibilities of adjournment. It is evident that if the "healthy" route consists in extending the route in a not reasonable factor, the optimal plan of an environmental point of view will be not used due to an excessive loss of the temporal constraint, that is to say: go instead of appointment as quickly as possible.

A pedestrian route consists of bows (streets, boulevards etc.), crossed in any sense or direction and from which the rate of pollution differs between every artery according to the car traffic, local climatic conditions and of the surrounding urban morphology, as we said previously.

The vulnerability of the pedestrian is a qualitative variable which is function of the age, the sex, the state of health, the sports activity of the person. The concentration in pollutants is estimated from complex calculations integrating the urban morphology (network and built), a database of traffic, a database of broadcasts, a database of climatology factors implemented in a model of dispersal of pollutants. The vulnerability of the persons is defined according to the following classes: 1 for little vulnerable, 2 for vulnerable and 3 for very vulnerable.

The method is partially based on construction of indicators, integrating into their formulation the polluting load of the chosen artery but also the length of this one, as well as the vulnerability of the pedestrian. Because, the more the artery is long, the more the fact that it is polluted is binding, the exposure time of the user being globally proportional to the length of the route and conversely proportional to the speed of movement. To inform every arc of the local area, an indicator of exposure was created.

The indicator set up for the calculation of optimization (the function "objective" to minimize) is the product (in constants near) of the present concentration of pollutants on the artery by its length and by the vulnerability of the considered person. Its theoretical formulation is the following one: $E=V.L.[C]$, where V is the vulnerability of the pedestrian, L the length of the borrowed arc, [C] the concentration in pollutants of the arc (for a specific pollutant).

Once this value is calculated and allocated to every bow of the local area, the implementation is made via the interface of the software Chronovia. From a technical point of view, the integration of multifactor constraints in the module of accessibility, implemented in the software of geographical information system (GIS) is not so easy; that why we have to create a specific plug - in. The principle of this type of tool is based on the theory of the graphs and the algorithm of the shortest road (Djkstra, Floyd - Warshall etc.), in distance, time or cost. Thus, the objective is to minimize the sum of the constraints.

Within the framework of a problem of distance, the sum of the distances to go of a knot to another knot must be minimal. It is the same problem for the studied environmental nuisance; it is a question of minimizing the environmental pressure undergone by the pedestrian; in other words minimize the sum of the arterial exposures, the exhibitions which also take into account the time which we need to walk on the axis and, of course the length of the axis.

The add-on Chronovia allows a very precise characterization of a public road network and these various users, this capacity was not used in our example, because our objective was not to reproduce a reality, but to use a theoretical case. The user of the network is configured to be a pedestrian who moves, on average, in a constant speed of five kilometres per hour. From the available information in the majority of the geographical databases on networks, Chronovia models the network in graph and calculates various indicators of accessibility and coherence. The tool is then capable of detecting an optimal route on the network according to the distance, the distance time and the economic cost, by taking into account factors of configuration of the network (structure, curve, flow) of the traffic at various hours; sense of traffic (circulation); traffic lights.

It is possible to attribute a cost of specific passage to every artery. To integrate the exposure indicator, we have planned to use the function of calculation of route according to an economic cost, by having beforehand replacing the cost by artery, by our indicator. But, Chronovia needs a fixed cost which, according to the distance, adds a value representing the cost of the gasoline; this fixed value which would have disrupted the detection of the optimal routes of an environmental point of view, obliged to us to integrate the indicator of exposure into the place of the distance, which is the only completely independent factor.

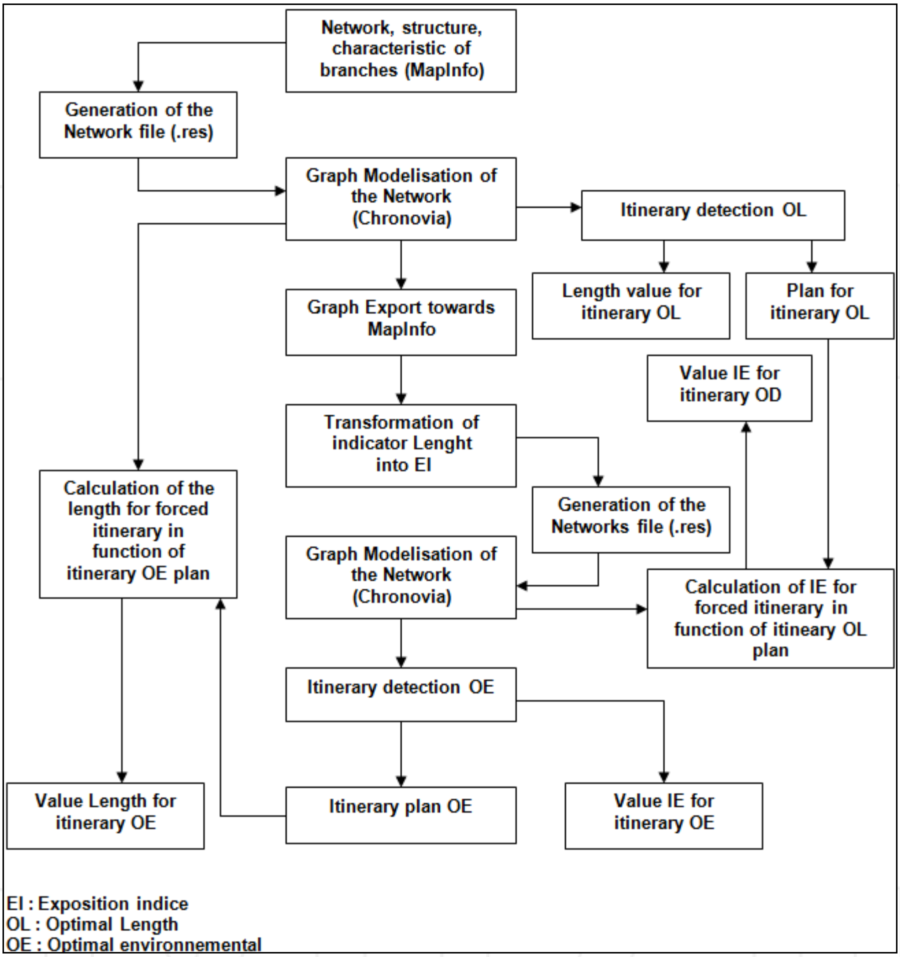

Fig. 5. Protocol of detection of route, calculation of the distances and the total exposure of the optimal plans.

This forced choice (by technical point of view), slightly complicated the protocol of calculation, presented in the figure 4 which follows. For every route [AB], we wished to obtain the plan of the optimal route, according to the distance, and according to the environmental exposure at the various levels of vulnerability; the crossed distance and to the total level of exposure for each of the plans.
In the figure 5, we speak about "calculation of itinerary forced in function of a plan", this expression deserves some precision. We wished to obtain the total value of exposure in pollutants for the optimal routes according to the distance. Now, as we said it previously, we had to replace the indicator outstrip to integrate our own indicator. The optimal routes

were calculated from two different graphs, the information available on the one not existing on the other one; from there, the question was how to calculate the value of the environmental exposure according to an optimal plan outstrip (OD)?

The detection of optimal route between A and B can be forced by the passage by some number of points on the network. To resolve our problem we used this function by constraining the itinerary to preselected knots of the network so as to reproduce the plan of the route OD on the graph where we had integrated the indicator of exposure into pollutants. We obtain then the information concerning the total distance and the global level of exposure for every plan of optimal route.

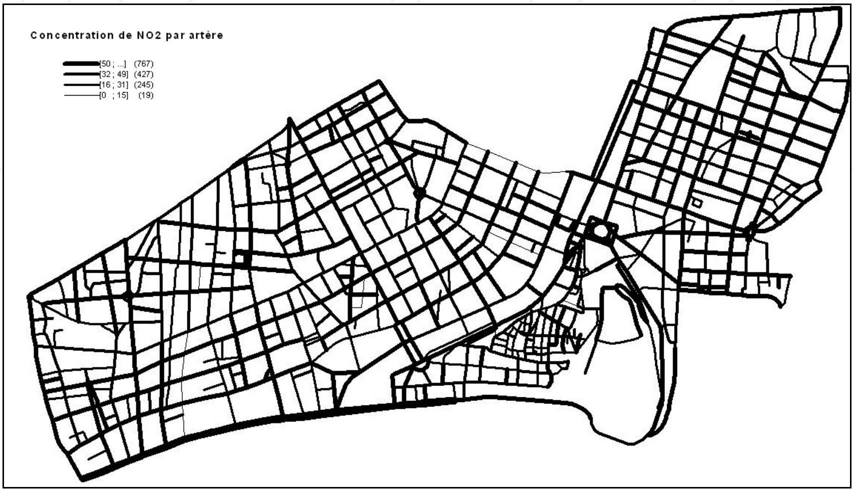

Fig. 6. Network branches and NO_2 concentration

Fig. 7. Optimal itinerary minimizing distance. (2,978km)

Fig. 8. Optimal itinerary minimizing environmental exposure for level pedestrian of vulnerability 1. (Distance = 3,223km; IE = 0,139)

Fig. 9. Optimal itinerary minimizing environmental exposure for level pedestrian of vulnerability 2. (Distance = 3,617km; IE = 0,263)

3. Conclusion

Through the concept of *optimality*; the operational elements of optimisation can be utilised for the construction of a more sustainable world. It must be seen as a key to reinterpreting the world. The notion "better" implicitly entails choosing "non-violence" when it comes to what exists already. This means, particularly in spatial planning, that we cannot simply forget our past actions and start from scratch. On the contrary, we must move already existing elements into a new order with a view to creating a new reality; a new reality which, in terms of complex collective criteria, we expect will be better. In terms of courses of action, this method (reframing what exists already) is much less intrusive and constitutes a new approach in prospective spatial planning. In this way, age-old questions which remain unanswered give life to the scientific activity of the moment. Michel Godet explains that “The world changes, yet problems remain [creating] an advantage for the thoughtful man: past efforts are hardly ever obsolete and in order to rediscover the majority of mechanisms and reports created in the past, all we need to do is bring them up to date using recent data” (Godet, 2000).

The problems of routes try systematically to optimize certain parameters as the time or the distance. We saw that it is possible to introduce new preoccupations into the choice of these routes as for example environmental issues (air quality on axes or still noise pollutions). The various parameters to be optimized can be combined in a multicriteria analysis with the ultimate purpose of which is to save some energy, under whatever forms whether it is. Energy savings are one of the main concerns of a better sustainable management of the environment.

Considering the steady rhythm of broadcasting of the technologies connected to the GPS (henceforth available on the GSM), it is very likely that in court or middle term of new generations of GPS are born. By adapting itself to the new practices of mobility in town, and by taking into account preoccupations of the populations, this new GPS could indeed integrate new among others environmental factors of optimization.

Other interest of the method, proposed in this chapter, lives in the coupling vulnerability of the persons - vulnerability of the urban axes in front of the polluting load. In the objective of a “requalification” of urban areas, in particular by the implementation of new pedestrian areas, or reduced traffic lanes, the quality of life of these spaces tends to improve, the notion of sustainable development underlying this evolution. So, the pedestrian would begin to find a place in town.

By means of feedback, it is going to improve the global quality of life of our cities. Indeed the pedestrian noticing an improvement of the environmental quality of certain taken routes will tend to favor the soft modes of movements and will so contribute to ameliorate the quality of life, the phenomenon similar to the entropy of a closed system. However, in terms of urban planning, we cannot give the whole street to the pedestrian. Some structuring axes of the city must be mainly dedicated to the automobile mobility. In this optics, the problem of environmental optimal routes takes a quite new bend: how is it possible to avoid the structuring axes knowing that these are penalizing from a public health point of view?

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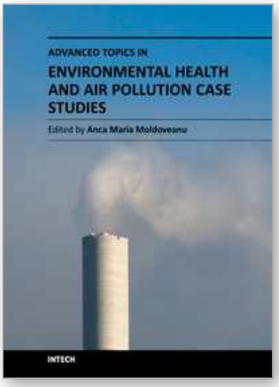

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The book describes the effects of air pollutants, from the indoor and outdoor spaces, on the human physiology. Air pollutants can influence inflammation biomarkers, can influence the pathogenesis of chronic cough, can influence reactive oxygen species (ROS) and can induce autonomic nervous system interactions that modulate cardiac oxidative stress and cardiac electrophysiological changes, can participate in the onset and exacerbation of upper respiratory and cardio-vascular diseases, can lead to the exacerbation of asthma and allergic diseases. The book also presents how the urban environment can influence and modify the impact of various pollutants on human health.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821